

What is claimed is:

1. A method for implanting ions in a surface layer of
5 a workpiece, comprising:

placing said workpiece on a workpiece support in a chamber with said surface layer being in facing relationship with a ceiling of said chamber, thereby defining a processing zone between said workpiece and said ceiling;

10 introducing into said chamber a process gas comprising the species to be implanted in said surface layer of said workpiece;

15 generating from said process gas a plasma by inductively coupling RF source power into said processing zone from an RF source power generator through an inductively coupled RF power applicator;

applying an RF bias from an RF bias generator to said workpiece support.

20 2. The method of Claim 1 wherein said RF bias has a bias frequency that is sufficiently low for ions in a plasma sheath near said workpiece to attain an ion energy at least nearly equivalent to a peak-to-peak voltage of said RF bias generator.

25 3. The method of Claim 2 wherein said bias frequency is sufficiently high so that RF voltage drops across dielectric layers on said workpiece do not exceed a predetermined fraction of an RF bias voltage applied to said 30 workpiece support by said RF bias generator.

4. The method of Claim 3 wherein said predetermined fraction corresponds to about 10%.

35 5. The method of Claim 1 further comprising setting said RF bias to a level corresponding to a desired depth in

said surface layer to which said element is to be implanted.

6. The method of Claim 5 wherein said surface layer comprises a semiconductor material, and said species to be implanted comprises a dopant impurity that promotes one of a p-type or n-type conductivity in said semiconductor material, and wherein said desired depth to which said element is to be implanted corresponds to a desired p-n junction depth.

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7. The method of Claim 6 wherein said gas comprises a chemical combination of said dopant impurity and another element.

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8. The method of Claim 7 wherein said gas comprises a fluoride of said dopant impurity.

9. The method of Claim 7 wherein said gas comprises a hydride of said dopant impurity.

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10. The method of Claim 7 wherein said gas further comprises a co-implant ion bombardment element which removes from a top surface of said surface layer a material that tends to accumulate during implantation of said dopant impurity.

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11. The method of Claim 1 wherein said surface layer comprises a semiconductor crystal which is to be implanted with a dopant impurity element, and wherein said species comprises a pre-implant ion bombardment species that creates damage in said semiconductor crystal for amorphizing said surface layer.

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12. The method of Claim 1 wherein said surface layer comprises a dielectric thin film, and wherein said species comprises a surface-enhancement species which enhances a

characteristic of said dielectric thin film layer upon implantation and substitution.

13. The method of Claim 12 wherein said characteristic
5 is the electrical behavior of said dielectric thin film.

14. The method of Claim 12 wherein said dielectric thin film comprises an oxide of a semiconductor element, and said species comprises a non-oxygen element to be
10 substituted for oxygen atoms in said dielectric thin film.

15. The method of Claim 1 wherein the step of placing said workpiece on said workpiece support is preceded by:
introducing a passivation process gas containing
15 passivation-forming chemical species;
forming a passivation layer on interior surfaces of said chamber by generating from said passivation gas a plasma in said processing zone.

20 16. The method of Claim 15 wherein said passivation gas comprises one of a hydride, a fluoride or an oxide of a semiconductor element.

25 17. The method of Claim 16 wherein said passivation gas comprises a chemical species containing carbon and fluorine.

18. The method of Claim 15 wherein the step of generating a plasma from said process gas is followed by:
30 removing said process gas from said chamber;
removing said workpiece from said chamber;
introducing a passivation layer-removing gas into said chamber;
generating from said passivation layer-removing
35 gas, a plasma in said processing zone, so as to remove said passivation layer from said interior surfaces of said

chamber.

19. The method of Claim 18 further comprising heating said interior surfaces of said chamber during the removal of
5 said passivation layer.

20. The method of Claim 18 wherein said passivation layer-removing gas comprises a fluorine-containing gas.

10 21. The method of Claim 18 wherein said passivation layer-removing gas comprises a hydrogen-containing gas.

22. The method of Claim 1 wherein the step of introducing said process gas is preceded by:
15 pre-cleaning said wafer.

23. The method of Claim 22 wherein the step of precleaning said wafer comprises removing an accumulated layer therefrom.

20 24. The method of Claim 23 wherein the step of removing comprises removing an oxide layer from said workpiece.

25 25. The method of Claim 24 wherein the step of removing an oxide layer comprises etching said oxide layer.

26. The method of Claim 1 wherein the step of generating a plasma from said process gas is followed by:
30 heating said surface layer of said workpiece to an anneal temperature sufficiently high to cause atoms of the species implanted in said surface layer to be substituted into atomic sites in a crystal lattice of said surface layer.

35 27. The method of Claim 26 wherein said surface layer

is masked by a photolithographic layer defining a pattern of ion implantation, and wherein the step of heating said surface is preceded by:

removing said photolithographic layer.

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28. The method of Claim 27 wherein the step of removing said photolithographic layer is carried out in a pyrolyzation chamber.

10 29. The method of Claim 26 wherein the step of heating said surface layer is carried out after removing said workpiece from said chamber and placing it in an anneal chamber.

15 30. The method of Claim 6 wherein said process gas is one of (a) hydride of said dopant species or (b) a fluoride of said dopant species, and said ion bombardment element comprises one of: Helium, Hydrogen, a semiconductor element of the type including Silicon, Germanium, Carbon, a fluoride 20 of a semiconductor element of the type including fluorides of Silicon, Germanium, Carbon.

31. The method of Claim 18 wherein said passivation layer-removing gas comprises NF3.

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32. The method of Claim 6 wherein said semiconductor material is silicon and said dopant impurity is boron.

33. The method of Claim 6 wherein said semiconductor 30 element is silicon and said dopant impurity is phosphorus.

34. The method of Claim 6 wherein said semiconductor element is silicon and said dopant impurity is arsenic.

35. The method of Claim 14 wherein said semiconductor element comprises one of silicon or germanium.

36. The method of Claim 1 wherein:
said surface layer comprises plural dielectric
gates formed over an underlying layer having horizontal and
5 non-horizontal surfaces;
the step of applying bias power comprises
selecting a level of said bias power promotive of a
sufficiently collisional plasma sheath over said workpiece
to produce a significant fraction of ions impacting said
10 surface layer at trajectories other than orthogonal to said
surface layer whereby to implant ions in said horizontal and
non-horizontal surfaces of said surface layer.

37. The method of Claim 6 wherein said surface layer
15 comprises a crystal lattice and wherein the step of
generating a plasma from said process gas is preceded by:

introducing into said chamber an amorphizing gas
comprising an ion bombardment species;

20 generating from said amorphizing gas a plasma in
said processing zone;

applying bias power to said workpiece support to
attract ions of said ion bombardment species from said
plasma toward said surface layer whereby said ions cause
damage in said crystal lattice to amorphize said crystal
25 lattice.

38. The method of Claim 37 wherein said ion
bombardment species comprises a semiconductive species.

30 39. The method of Claim 38 wherein said ion
bombardment species comprises one of silicon or germanium.

40. The method of Claim 7 wherein said process gas
further comprises an ion bombardment species for co-
35 implantation with said dopant impurity in said surface
layer.

41. The method of Claim 40 wherein ions of said ion bombardment species are implanted in said surface layer to cause crystal lattice damage for amorphizing said surface 5 layer during implantation of said dopant impurity in said surface layer.

42. The method of Claim 41 wherein said ion bombardment species comprises a semiconductor species.

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43. The method of Claim 42 wherein said semiconductor species comprises one of silicon or germanium.

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44. The method of Claim 1 wherein said bias comprises RF power.

45. The method of Claim 44 further comprising pulse modulating said RF bias power.

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46. The method of Claim 45 further comprising pulse modulating said RF source power.

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47. The method of Claim 46 further comprising maintaining a relation between the pulse modulating of said RF bias power and the pulse modulating of said RF source power that is one of:

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- (a) push-pull;
- (b) in-synchronism;
- (c) symmetrical;
- (d) non-symmetrical.

48. The method of Claim 1 wherein the step of applying said bias power comprises applying a single burst of said bias power to said workpiece support.

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49. The method of Claim 48 wherein said single burst

has a duration corresponding to a desired implant dosage.

50. The method of Claim 49 further comprising:
sensing when a voltage measured near said
5 workpiece support reaches a threshold corresponding to the
desired implant depth in response to applying said bias
power;

triggering a clock in response to said sensing
step, and terminating said bias power when said clock
10 reaches said duration.

51. The method of Claim 44 further comprising
controlling said bias power so as to produce a bias voltage
near said workpiece support at least nearly equal to said
15 threshold.

52. The method of Claim 1 wherein said RF bias
generator has a bias frequency that is sufficiently low for
ions in a plasma sheath near said workpiece to follow
20 electric field oscillations across said sheath at said bias
frequency.

53. The method of Claim 52 wherein said bias frequency
is sufficiently high so that RF voltage drops across
25 dielectric layers on said workpiece do not exceed a
predetermined fraction of the RF bias voltage applied to
said workpiece support.

54. The method of Claim 53 wherein said predetermined
30 fraction corresponds to about 10%.

55. The method of Claim 1 wherein said RF bias
generator has a bias frequency between 10 kHz and 10 MHz.

35 56. The method of Claim 1 wherein said RF bias
generator has a bias frequency between 50 kHz and 5 MHz.

57. The method of Claim 1 wherein said RF bias generator has a bias frequency between 100 kHz and 3 MHz.

5 58. The method of Claim 1 wherein said RF bias generator has a bias frequency of about 2 MHz to within about 5%.

10 59. The method of Claim 1 wherein said species to be implanted comprises a first atomic element, said process gas further comprising:

15 a second atomic element in chemical combination with said first atomic element.

15 60. The method of Claim 59 wherein said surface layer of said workpiece is a semiconductor material and said first atomic element is an n-type or p-type conductivity dopant impurity with respect to said semiconductor material.

20 61. The method of Claim 60 wherein said second atomic element comprises a semiconductor element.

25 62. The method of Claim 61 wherein said second atomic element and said semiconductor material of said surface layer are the same atomic element.

30 63. The method of Claim 60 wherein said second atomic element is an element having a greater tendency than said first atomic element following ion implantation to diffuse out of said surface layer upon heating of said surface layer.

64. The method of Claim 60 wherein said second atomic element comprises one of hydrogen and fluorine.

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65. The method of Claim 60 wherein the chemical

combination of said first and second atomic species comprises a first molecular species, said process gas further comprising a second molecular species.

5 66. The method of Claim 65 wherein said second molecular species comprises one of: (a) hydrogen gas, (b) fluorine-containing gas.

10 67. The method of Claim 64 wherein said first molecular species comprises a fluoride of said dopant impurity and said second molecular species comprises a hydride of said dopant impurity.

15 68. The method of Claim 67 wherein said process gas further comprises a third molecular species.

20 69. The method of Claim 68 wherein said third molecular species comprises at least one of (a) hydrogen-containing gas, (b) fluorine-containing gas, (c) an inert gas.

70. The method of Claim 1 further comprising:
 providing a cleaning plasma species source reactor;
25 prior to the step of introducing said workpiece, producing a plasma in said cleaning species source reactor from chamber cleaning species precursor gases to produce chamber cleaning plasma species;
 furnishing said chamber cleaning plasma species
30 from said cleaning species source reactor into said plasma immersion ion implantation reactor so as to clean interior surfaces of said plasma reactor, and then removing said chamber-cleaning plasma species from said plasma immersion ion implantation reactor.

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71. The method of Claim 70 wherein said chamber

cleaning precursor gases comprise a fluorine-containing species and said chamber cleaning plasma species comprise fluorine-containing radicals.

5 72. The method of claim 70 wherein said chamber cleaning precursor gases comprise a hydrogen-containing species and said chamber cleaning plasma species comprise hydrogen-containing radicals.

10 73. The method of Claim 1 further comprising:
 providing an optical metrology chamber;
 obtaining a measurement of ion implantation in a workpiece previously processed in said plasma immersion ion implantation reactor;
15 adjusting said magnitude of said bias in accordance with said measurement.

20 74. The method of Claim 1 further comprising:
 providing an ion beam implantation apparatus;
 placing said workpiece in said ion beam implantation apparatus and implanting a second species in said surface layer.

25 75. The method of Claim 74 wherein said surface layer is a semiconductor material, and said first and second species are dopant impurities of opposite conductivity types relative to said semiconductor material.

30 76. The method of Claim 75 further comprising:
 masking devices on said workpiece of one conductivity type and exposing devices of an opposite conductivity type during ion implantation of said first species in said plasma immersion ion implantation reactor;
 masking devices on said workpiece of said opposite conductivity type and exposing devices of the one conductivity type during ion implantation of said second

species in said ion beam implantation apparatus.

77. The method of Claim 76 wherein said first species is of a lower mass than said second species.

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78. The method of Claim 76 wherein said first species comprises boron and said second species comprises arsenic.

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79. The method of Claim 1 further comprising:

providing an anneal chamber;

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after the step of generating a plasma, removing said workpiece from said plasma immersion ion implantation reactor and placing it in said anneal chamber, and heating said surface layer sufficiently to cause at least some of the species ion implanted in said surface layer to be substituted into crystal lattice atomic sites of said surface layer.

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80. The method of Claim 79 wherein the step of heating comprises a dynamic surface anneal process.

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81. The method of Claim 1 further comprising:

providing a photoresist strip chamber;

the step generating a plasma is followed by

placing said workpiece in said photoresist strip chamber and removing photoresist from said workpiece.

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82. The method of Claim 1 further comprising:

providing a wet clean chamber;

and wherein the step of generating said plasma is followed by placing said workpiece in said wet clean chamber.

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83. The method of Claim 1 further comprising:

providing a second plasma immersion ion implantation reactor;

placing said workpiece in said second plasma immersion ion implantation reactor and implanting a second species in said surface layer.

5 84. The method of Claim 83 wherein said surface layer is a semiconductor material, and said first and second species are dopant impurities of opposite conductivity types relative to said semiconductor material.

10 85. The method of Claim 84 further comprising:
masking devices on said workpiece of one conductivity type and exposing devices of an opposite conductivity type during ion implantation of said first species in said plasma immersion ion implantation reactor;

15 masking devices on said workpiece of said opposite conductivity type and exposing devices of the one conductivity type during ion implantation of said second species in said second plasma immersion ion implantation reactor.

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